The Shapes and Phases of Small Particles in Mixed-Phase Clouds

Research Highlight

Mixed-phase clouds, in which supercooled water droplets and ice crystals co-exist, are ubiquitous throughout the troposphere over all regions of the Earth, and especially over polar regions. Because these clouds are radiatively significant, because radiative properties depend significantly on particle phase, and because particles with maximum dimensions D < 60 micrometers contribute up to 50% of the total extinction, it is important to know what controls the phases of small particles in mixed-phase clouds. In this study, 2.3 micrometer resolution observations of particles in mixed-phase clouds obtained from a Cloud Particle Imager (CPI) in DOE field campaigns over the Arctic are used to explore the relationship between cloud particle shape/phase and bulk microphysical properties such as the ratio of the liquid water content (LWC) to the total water content (TWC).

Data obtained in the pristine fall season during the 2004 Mixed-Phase Arctic Cloud Experiment (M-PACE) and in the more polluted spring season during the 2008 Indirect and Semi-Direct Aerosol Campaign (ISDAC) are used. Using images of cloud droplets obtained in liquid conditions, it was shown that the differing optical characteristics of the CPIs used in M-PACE and ISDAC had no impact on measures of crystal morphology provided that D > 35 micrometers and the focus > 45. Figure 1 shows that the shape of small cloud particles in liquid dominated clouds (i.e., LWC/TWC > 0.9) was frequently more circular than those obtained in ice-dominated conditions (i.e., LWC/TWC < 0.1). An automated analysis of all particles with 35 micrometers < D < 60 micrometers and focus > 45 in conditions with minimal shattering on the CPI tube showed that the fraction of particles with area ratio (projected area of particle divided by area of circumscribed circle with diameter of particle maximum dimension) > 0.8 increased with the LWC/TWC ratio.

The average area ratio of small particles in a 10-s interval in mixed-phase clouds was correlated with LWC/TWC with a correlation coefficient of 0.60 for M-PACE and 0.43 for ISDAC. The stronger correlation seen during M-PACE compared to ISDAC was most likely associated with the presence of more liquid droplets that were larger than the CPI detection threshold as the model effective radius was larger during M-PACE (11 compared to 6 micrometers) and drops with D > 35 micrometers had concentrations 6 times larger during M-PACE. This is consistent with higher aerosol concentrations in ISDAC causing more numerous and smaller cloud droplets. Figure 2 shows that the correlation between the mean area ratio and LWC/TWC was much higher when the effective radius was > 5 micrometers for both M-PACE and ISDAC, regardless of the temperature over which the data were obtained.

One of the most important findings of this study is that an assumption made in the development of many parameterization schemes, that all small particles in mixed-phase clouds are supercooled water, is not true. This conclusion may have important ramifications for the development of future model parameterization schemes that are needed to physically represent single-scattering and fallout processes that are important for determining the radiative influence of mixed-phase clouds. Further, its impact on the development and evaluation of retrieval schemes from ground- and satellite-based remote sensors is important.

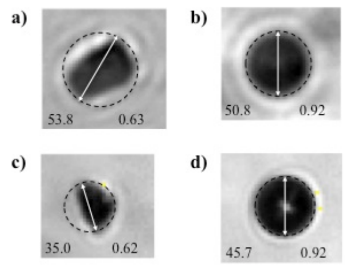

Figure 1. Magnified images of four particles imaged during M-PACE and ISDAC. The Dmax (micrometers) and area ratio for each particle are embedded in each image; the actual Dmax (white arrow) and the circumscribed circle (dashed line) used to calculate area ratio are also shown in each image. a) and c) from ice-dominated conditions; b) and d) from liquid-dominated conditions.

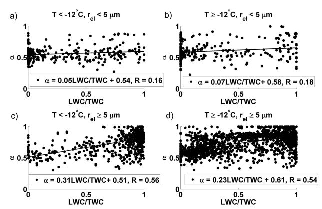

Figure 2. Mean area ratio averaged over all particles with 35 < D < 60 micrometers and focus > 45 in given 10-s interval as function of LWC/TWC for all mixed-phase clouds sampled during M-PACE and ISDAC; different plots correspond to time periods with the following conditions: a) T <-12 Celsius and re < 5 micrometers; b) T > -12 Celsius and re < 5 micrometers; c) T < -12 Celsius and re > 5 micrometers; d) T > -12 Celsius and re > 5 micrometers.

Reference(s)

McFarquhar GM, J Um, and R Jackson. 2013. "Small cloud particle shapes in mixed-phase clouds." Journal of Applied Meteorology and Climatology, 52(5), doi:10.1175/JAMC-D-12-0114.1.

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